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AND TELEMAMMOGRAPHY

PRINCIPAL INVESTIGATOR: Matthew Freedman, M.D.

CONTRACTING ORGANIZATION: Georgetown University
37th and O Streets, NW
Washington, DC 20057

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6. AUTHOR(S) Matthew Freedman, M.D.
Department of Radiology, Georgetown University Hospital
3800 Reservoir Road, N.W.
Washington, DC 20007

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Georgetown University 37th & O Streets N.W. Washington, DC 20057	8. PERFORMING ORGANIZATION REPORT NUMBER RX 4300 820
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The project has two goals: the implementation of a computer based program of mammographic quality analysis and control and an evaluation of the feasibility of telemammography. Computer aided quality control will allow the technologist to be informed by the computer whether or not common faults in exposure are present in the mammographic image and indicate to her the desirability of obtaining additional views such as compression spot views or magnification spot views prior to the patient leaving the facility.

We have defined exposure factors needed to assure proper exposure with both screen film and direct digital mammography and are in the process of transferring this information into a computer program for computer assisted quality control. We have acquired a database of approximately 50 misexposed cases. Our microcalcification program now has an Az of 0.88. We have a database of 42 microcalcification cases each with biopsy proof to test the system.

We have successfully transmitted a digitized film mammogram 900+ miles to a laser printer. Development of a workstation for displaying telemammography is underway. Tests will be performed during the current year to confirm statistically the clinical

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FOREWORD

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4. TABLE OF CONTENTS

1. FRONT COVER
2. SF 298
3. FORWARD
5. INTRODUCTION
6. BODY OF REPORT:
 - 6.1 QUALITY CONTROL: OBTAINING THE PROPER EXPOSURE:
 - 6.1.1 COMMON CAUSES OF EXPOSURE ERROR
 - 6.1.2 METHOD OF ASSESSING PROPER EXPOSURE
 - 6.1.3 LOCAL VERSUS GENERALIZED EXPOSURE ERRORS:
 - 6.1.4 COMPARING SCREEN FILM AND DIGITAL IMAGING IN GEOMETRIC TEST OBJECTS:
SELECTING THE REQUIRED EXPOSURE LEVEL
 - 6.1.5 PROJECTS FOR 1995 RELATED TO EXPOSURE CONTROL
 - 6.1.6 SOFTWARE PROGRAM DESIGN
 - 6.1.7 CLINICAL DATA SET FOR REGIONS OF MISEXPOSURE
 - 6.2 REGIONS OF MICROCALCIFICATION CLUSTERS THAT MAY REQUIRE MAGNIFICATION
SPOT VIEWS
 - 6.3 TELEMAMMOGRAPHY
 - 6.3.1 PROGRESS DURING 1994
 - 6.3.1.1 TELEMAMMOGRAPHY TEST
 - 6.3.1.2 WORKSTATION DISPLAY
 - 6.3.3 TELEMAMMOGRAPHY DEMONSTRATION
 - 6.4 COLLEGIAL RELATIONSHIP WITH DOD PHYSICIANS
 - 6.5 PLAN OF WORK FOR 1995
 - 6.5.1 QUALITY CONTROL SYSTEM
 - 6.5.1.1 SOFTWARE DEVELOPMENT
 - 6.5.1.2 TEST CASE COLLECTION
 - 6.5.1.3 TESTS OF A SCREEN FILM SYSTEM WITH DIFFERENT LATITUDE
 - 6.5.1.4 MICROCALCIFICATION DETECTION SOFTWARE
 - 6.5.2 TELEMAMMOGRAPHY

6.5.2.1 CONTINUED WORKSTATION DEVELOPMENT

6.5.2.2 TELEMAMMOGRAPHY DEMONSTRATION

7 CONCLUSIONS

8. BIBLIOGRAPHY

5. INTRODUCTION

The project has two goals: the implementation of a computer based program of mammographic quality analysis and control and an evaluation of the feasibility of telemammography. Computer aided quality control will allow the technologist to be informed by the computer whether or not common faults in exposure are present in the mammographic image and indicate to her the desirability of obtaining additional views such as compression spot views or magnification spot views prior to the patient leaving the facility. The evaluation of the feasibility of telemammography will involve the development of appropriate techniques for the transmission of mammograms to a remote site for interpretation and the display of the images on an MDIS type workstation, if that can be shown to be of appropriate quality, and as laser prints.

6. BODY OF REPORT:

6.1 QUALITY CONTROL: OBTAINING THE PROPER EXPOSURE:

6.1.1 COMMON CAUSES OF EXPOSURE ERROR

Under and over exposed images of the breast can conceal the signs of breast cancer. Although breast images are phototimed, the exposure resulting can be incorrect because of several factors; the technologist must (1) correctly position the breast in relation to the phototimer, (2) correctly select the position of the phototimer in relation to the position of residual glandular tissue within the breast, (3) correctly select the KVP for the breast composition and thickness and (4) use adequate breast compression. Skilled technologists make occasional mistakes in these tasks and technologists who do mammography less frequently are more likely to make such mistakes.

6.1.2 METHOD OF ASSESSING PROPER EXPOSURE

Assessing the exposure that actually reaches the image detector (film or digital) allows one to estimate the quality of the final image. An image that is underexposed contains less information in regions of underexposure than does a properly exposed image. One can estimate the required exposure by measurement of the information content of images of geometric test objects obtained at varying exposures, convert the data into digital form and measure pixel values. One can then compare the pixel value in clinical images to those obtained in geometric test objects to determine whether the clinical images are in an exposure range that contains full information.

As an example, we obtained screen film and storage phosphor images of the Nuclear Associates CDMAM and the CIRS Detail Phantoms. These images were obtained at 28 KVP with mAs varied between 6 and 40 mAs. The objects detectable on these images of phantoms are then recorded. We found that on screen film images of the CDMAM phantom, that exposures less than 12 mAs resulted in some loss of information. The next step will be to digitize the screen film image so that the resulting pixel values can be measured. In the same way, the digital images will be transferred from the storage phosphor device to our analysis computer and the pixel values correlated with the information content of the images. (We are awaiting the interface board from Japan to allow us to study the digital images in this way.)

6.1.3 LOCAL VERSUS GENERALIZED EXPOSURE ERRORS:

The effects of misexposure can affect the entire image or occur only in sections of an image. In breasts that have a heterogeneous or dense pattern, there can be focal areas in which the exposure is low enough that the contrast of microcalcifications associated with cancer and occasionally small masses can be hidden. Assessing for focal areas of underexposure is part of the radiologists quality control tasks. When a radiologist identifies a focal area of underexposure, the patient often must be called back to obtain a compression spot film--to make the region of underexposure thinner and therefore less dense and therefore of better exposure and contrast.

In conventional screen film mammography, one can assess the adequacy of exposure quantity (mAs) by measuring optical density in regions of possible underexposure and comparing this to the characteristic curve of the film. One would want any region that might contain microcalcifications to be in a region where the characteristic curve is steep, indicating maximal contrast, rather than in a region near the low exposure "toe" of the characteristic curve, where contrast is less.

In digital systems, we are aware of no preexisting method for determining adequate regional exposure. In the digital system, a change in the look up table can increase the optical density of an image, but only partially restores the information in that image. One must therefore look at the original pixel values in an image data set to determine levels below which incomplete information is present. We have accumulated data in geometric test objects that will allow such calculations to be made both for digitized film mammograms and to direct digital mammograms obtained on our experimental storage phosphor digital mammography machine.

6.1.4 COMPARING SCREEN FILM AND DIGITAL IMAGING IN GEOMETRIC TEST OBJECTS: SELECTING THE REQUIRED EXPOSURE LEVEL

During this year work has been done to define the exposure levels within which full information is present in screen-film and in digital mammography. This was accomplished by obtaining images of geometric test objects in both screen film and digital systems and quantifying the information present in the images. These tests showed that there was a range of exposure below which full information was not present. In the screen film images this corresponded to an optical density less than 0.5 OD units or above 2.7 OD units. (The upper range of OD varies with the ambient room light and thus is only an approximate value for clinical use.) In the digital system using storage phosphor technology we found that the information content continued to increase up to exposures 4 times those used for conventional mammography (i.e. if the proper exposure for screen film was 28 KVP at 20 mAs, improvement was seen in the digital system at 28 KVP up to 80 mAs, but additional improvement was not seen at 120 mAs). When the exposure used for digital and screen films images was the same, but selected to be optimal for the screen film image, the digital images could be made to equal the small object detectability of screen film. An interesting finding was that at exposures below the optimal level for screen film mammography, the digital systems performed better than screen film, but still not at the digital optimal level.

Our intent in testing for the optimal exposure range was to provide data for the computer analysis QC program. The ability of the digital system to continue to improve in diagnostic level and even exceed the information content of screen film mammography with exposures higher than screen film mammography makes it difficult to select the level at which a repeat digital image should be recommended. The required exposure level for screen film mammography was made clear by these tests for the screen film system we are now using. As we digitize our screen film images we will determine the pixel values for images that contain full information or less than full information to determine the limits for the computer QC program.

A paper on exposure effects in digital mammography has been accepted for presentation at the SPIE Medical Imaging Conference, February, 1995, and will be published in their proceedings. This paper will discuss in more detail the findings of our exposure tests in two different geometric test objects as KVP and mAs were varied within clinically relevant ranges.

6.1.5 PROJECTS FOR 1995 RELATED TO EXPOSURE CONTROL

Additional evaluation of exposure parameters is still needed. It is our intention during this coming year to proceed in two ways

- a. To look at a second screen film system with a different latitude to determine whether the desired exposure range is similar to the film we tested (i.e. is the cut off point for full information at the same OD level, or must one adjust that level for each screen film system that is in clinical use). The images for this test have been collected, but not yet completely analyzed.
- b. To continue to design the computer program that will extract regions of the image whose exposure level falls below the critical level so that these regions can be marked for the technologist to obtain either a repeat standard exposure or a compression spot view of the region. The initial components of this have been made with a program to segment the breast and to plot the histogram.

6.1.6 SOFTWARE PROGRAM DESIGN

The current conceptual design that is serving as the model for the program designer is that the image of the breast should be segmented from the remainder of the image. That this segmented image should have both a global and multiple regional histograms measured. That these regions should measure approximately 2 cm in size so that regions of under or overexposure exceeding 2 cm in size will be detected. That the histograms in the region

should be analyzed to detect regional under or over exposure. The global histogram analysis will be used to detect lack of sufficient contrast so that lack of adequate compression and incorrect KVP effects on contrast will be detectable. Areas of regional underexposure will indicate the need for a compression spot view if they are few in number or repeat exposure with a different phototimer density setting if they are multiple.

6.1.7 CLINICAL DATA SET FOR REGIONS OF MISEXPOSURE

During this year, clinical cases have been identified with technical errors in exposure and have been maintained in a log book. Currently approximately 50 images are in this dataset. Once the software program is ready, we will have sufficient cases with both generalized and regional areas of proper and improper exposure with which to test the algorithm.

6.2 REGIONS OF MICROCALCIFICATION CLUSTERS THAT MAY REQUIRE MAGNIFICATION SPOT VIEWS

Magnification spot views are used when small clusters of microcalcifications are present. If the microcalcifications are numerous and clearly malignant, a magnification view is not needed, but when a small number is seen (the number used as the criteria for a magnification view varies among radiologists) such as 3 to 10 microcalcifications, magnification views are often desired. We have been working to develop a program to detect microcalcifications and a separate program to assess by their pattern their potential for being associated with cancer. Both programs incorporate neural networks in the decision processes. The development of these programs receives other support, the application of the microcalcification detection program for image QC is part of this project.

The program for microcalcification detection is now functioning with an accuracy as measured by Az of 0.88. Software for improved display of the location of microcalcifications is now under development. Once this software is ready, it will be incorporated into the QC program.

6.3 TELEMAMMOGRAPHY

6.3.1 PROGRESS DURING 1994

6.3.1.1 TELEMAMMOGRAPHY TEST

During the year we worked on development of a system for telemammography. May 28, 1994, we successfully transmitted over Internet a digitized film mammogram to a laser printer 900+ miles away. During the remainder of the year we continued to transmit images to test various components of a digital imaging system.

6.3.1.2 WORKSTATION DISPLAY

Our tests of image quality of mammographic display on workstations demonstrated that we could not capture full information in a clinically useful pattern on a 1.5 x 2 K workstation because of a lack of sufficient matrix size. 2 x 2.5 K appears to be necessary. The image processing parameters available on the MDIS workstation were tested and appear likely to be sufficient if a 2 K x 2.5 K monitor was used for display; however, our tests suggest that software beyond that available with the MDIS system may offer additional advantages. Low resolution histogram equalization combined with a higher contrast look up table improves the visibility of microcalcifications in laser prints and may also improve the demonstration of microcalcifications on workstations. We are currently working on such software for workstation display.

The display speed of the MDIS workstation would be too slow for a clinically useful screening mammography system. Because of this, during the year, we have been developing a 4 monitor research workstation to test the capabilities of direct soft copy reading of telemammograms. This is a 4 monitor 2 x 2.5 K system. It has the capability of displaying a 2 x 2.5 K digital mammogram in 0.5 seconds. Current image processing capability includes unsharp masking, band pass filtering and windowing. Currently we are working to improve the human interface programs. The system is currently undergoing testing prior to initiating a comparative test of digital mammograms. Preliminary tests indicate that the system is probably sufficient to demonstrate the smallest microcalcifications probably close to if not equal to the quality of screen film, but further testing is necessary. We are slightly behind schedule in fully testing the quality of display on this 2K x 2.5 K system because of delays

in the delivery of equipment; however the missing piece of equipment was delivered and installed the first week of January, 1995.

6.3.3 TELEMAMMOGRAPHY DEMONSTRATION

We have scheduled a telemammography demonstration for March 27-29, 1995, with transmission to a 2 K x 2.5 K workstation. During this demonstration we expect to transmit between 50 to 100 mammograms over a T-1 link.

6.4 COLLEGIAL RELATIONSHIP WITH DOD PHYSICIANS

Collegial relationship with Military Medical Facilities: Major Donald Smith, M.D. at Madigan Army Medical Center has been an active participant in this project. We have had multiple discussions during this project on the requirements for digital mammography in the MDIS environment. Dr. Smith prepared an extensive document detailing his recommendations for the project and has reviewed our plans. The final soft copy display system will be an amalgam of this joint input. Our joint decision is that the MDIS workstation is not well designed for the rapid throughput needed for soft copy interpretation of mammography and that a specialty workstation will probably be required to achieve adequate radiologist productivity. The results of our joint design will incorporate the concepts being tested in our experimental four screen workstation which will be programmed to present the images in a design that we believe will provide maximal productivity.

6.5 PLAN OF WORK FOR 1995

6.5.1 QUALITY CONTROL SYSTEM

6.5.1.1 SOFTWARE DEVELOPMENT

Continued activities will be made to complete the software for testing. Two different groups of software will be further refined and integrated:

- a. Exposure QC analysis software
- b. Microcalcification detection software.

6.5.1.2 TEST CASE COLLECTION

We will continue to collect cases of misexposure for inclusion in our development and testing database. We currently have approximately 50 misexposed images and plan to have acquired an additional 50 by the summer. We have available large numbers of properly exposed mammograms and will select 100 examples for comparison. This should provide an adequate data set on which to test the program.

6.5.1.3 TESTS OF A SCREEN FILM SYSTEM WITH DIFFERENT LATITUDE

We have acquired the images of geometric test objects needed to determine whether or not the exposure criteria we have derived using one screen film system is applicable to screen film images obtained on a different latitude system will be analyzed and their results compared to the data from the first set. This should help determine whether the QC program will need to be adjustable for the screen film system used in each institution. Analysis of this data should be complete by March, 1995.

6.5.1.4 MICROCALCIFICATION DETECTION SOFTWARE

This software is undergoing continued development in our laboratory. It is expected that this program will be ready for testing as part of this project by April, 1995. Once the program is ready, it will be combined with the exposure QC program so that the two systems can be tested together on the same database.

6.5.2 TELEMAMMOGRAPHY

6.5.2.1 CONTINUED WORKSTATION DEVELOPMENT

The development of an optimized workstation for digital mammography will continue. We anticipate testing the quality of display during the first few months of 1995 in geometric test objects and in selected clinical cases.

6.5.2.2 TELEMAMMOGRAPHY DEMONSTRATION

We will be performing a demonstration of telemammography in March 1995 with the expectation that we will be transmitting 50 to 100 digital breast images. We will be performing a statistical study during this year comparing the original images to digitized images to evaluate any effects that digitization of images and soft copy display may have on image diagnostic information using both geometric test objects and clinical proven cases.

7 CONCLUSIONS

Progress towards the development of a computer based method of assessing the quality of mammography images is continuing with the development of the data needed to assess for proper exposure and for the detection of microcalcifications. A dataset of misexposed images is being collected with approximately 50 images now included. We also have a proven set of 42 cases with biopsy proved breast microcalcification clusters.

Telemammography has been successfully performed with the transmission of a digitized film mammogram 900+ miles. Additional development for workstation display of transmitted mammograms and for their laser printing still needs to be done and a test that the transmitted images are sufficient for interpretation must be performed. We have acquired an adequate sized database for this test and will be performing it during the final year of this project.

8. BIBLIOGRAPHY

The following is a list of publications from our research group related to digital imaging for mammography:

Proceedings/Transactions

Lo S-C B, Freedman M, Stewart D, Mun S K: Contrast Characteristics on CRT Display Monitor. IMAC 91, Kyoto, Japan (April 11-13, 1991); 342-347pp.

Dawkins T, Freedman M, Lo S-C B, Mun S K: 35 Micron CCD Based Film Digiter for Mammography. SPIE Poster. SPIE Medical Imaging paper 1897-53 (February 1993).

Freedman M, Mun S K, Pe E, Lo S-C B, Nelson M: Image Optimization on the Fuji AC-1 SPIE: Medical Imaging (1993). Paper 1897-51.

Freedman M, Mun S K, Pe E, Weiser J C, Roblein J R, Lo S-C B, Nelson M: Quality Control of Storage Phosphor Imaging Devices. CAR 93, 7th International Symposium Berlin (June 24-26, 1993); 456-460pp.

Freedman M, Pe E, Nelson M, Lo S-C B, Mun S K: Digital Mammography: Demonstration of a Method of Achieving Adequate Resolution on a Storage Phosphor System. CAR 93, 7th International Symposium Berlin (June 24-26, 1993); 783pp.

Wu Y C, Lo S-C B, Zuurbier R, Hasegawa A, Freedman M, Mun S K: Classification of Microcalcifications Using A Hybrid Neural Network. SPIE: Medical Imaging (February 1994). Paper 2167-61.

Fields F, Freedman M, Lo S-C B, Zuurbier R, Nelson M, Mun S K: Comparison of Conventional Film Screen Magnification Mammography and Electronic Magnification. SPIE: Medical Imaging (February 1994). Paper 2167-67.

Freedman M, Pe E, Zuurbier R, Katial R, Jafroudi H, Nelson M, Lo S-C B, Mun S K: Image Processing in Digital Mammography. SPIE: Medical Imaging, Vol. 2164 (1994); 537-554pp.

ABSTRACTS

Lo S-C B, Wu Y, Hasegawa A, Freedman M, Mun S K: Fuzzy Neural Network and Fuzzy System Modeling for General Medical Image Pattern Recognition (abstract). Radiology (1993); 189P:219.

Freedman M, Pe E, Mun S K, Nelson M: Method For Optimizing Images In A Storage Phosphor Imaging Device (abstract). Radiology (1993); 189P:413.

Freedman M, Zuurbier R, Pe E, Jafroudi H, Mun S K, Lo S-C B: Image Processing In Digital Mammography (abstract). Radiology (1993); 189P:408.

Freedman M T, Steller D E, Hasegawa A, Zuurbier R A, Wu Y C, Smith D V, et al: Image Processing in Digital Mammography (abstract). Radiology (1994); 193(P):474.

Freedman M T, Steller D E, Zuurbier R A, Jafroudi H, Mun S K: Experimental Digital Mammography in the Detection of Microcalcifications 300 mm and smaller (abstract). Radiology (1994); 193(P):422.

Lo S B, Butson P D, Lin J, Li H, Freedman M T, Mun S K: Performance Characteristics of High-Resolution Charge-Coupled-Device Film Imagers (abstract). Radiology (1994); 193(P):282.

Lo S B, Wu Y C, Freedman M T, Mun S K, Hasegawa A: Detection of Microcalcifications by Using Adaptive-sized Neural Networks (abstract). Radiology (1994); 193(P):171.

The following are presentations accepted from our group related to digital mammography that will be presented at SPIE Medical Imaging, 1995 and published in their proceedings.

Chan H-P, Wei D, Lam K, Lo S-C B, Helvie M A, Adler D D: Computerized Detection and Classification of Microcalcifications on Mammograms. SPIE: Medical Imaging (1995). Paper 2434-70.

Freedman M, Steller D, Jafroudi H, Lo S-C B, Zuurbier R, Katial R, Hayes W, Wu Y C, Lin J-S J, Mun S K: Digital Mammography: Effects of Decreased Exposure. SPIE: Medical Imaging (1995). Paper 2432-49.

Freedman M, Steller D, Jafroudi H, Lo S-C B, Zuurbier R, Katial R, Hayes W, Wu Y C, Lin J-S J, Steinman R, Tohme W G, Mun S K: Digital Mammography: Tradeoffs Between 50-and 100-micron Pixel Size. SPIE: Medical Imaging (1995). Paper 2432-09.

Hasegawa A, Lo S-C B, Wu Y C, Lin J-S J, Freedman M, Mun S K: Adaptive-size Neural-networks-based Computer-aided Diagnosis of Microcalcifications. SPIE: Medical Imaging (1995). Paper 2434-63.

Jafroudi H, Jennings R J: Multiparameter Optimization of Mammography with Alternative X-ray Sources. SPIE: Medical Imaging (1995). Paper 2432-10.

Jafroudi H, Steller D, Freedman M, Mun S K: Quality Control on Storage Phosphor Digital Radiography System. SPIE: Medical Imaging (1995). Paper 2432-59.

Lo S-C B, Li H, Lin J-S J, Hasegawa A, Wu Y C: Artificial Visual Neural Network with Wavelet Kernekls for General Disease Pattern Recognition. SPIE: Medical Imaging (1995). Paper 2434-66.

Steller D, Jafroudi H, Freedman M, Mun S K: Performance and Maintenance of Storage Phosphor Plates and Cassettes in Digital Radiography. SPIE: Medical Imaging (1995). Paper 2432-60.